A Further Look at Potential Impact of Satlets on Design, Production, and Cost of Satellite Systems

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Phoenix project was created to address and change the cost of mass, by shifting to on-orbit assembly and aggregation…

Traditional Space Segment Costs

Segment	Cost
Payload	$120k / kg
Bus	$120k / kg
Launch (per mass)	$10-30k/ kg, LEO-GEO
Ops	$Fixed /hr

Terrestrial Realm

Manufactured Modules

photo by JB Spector / Museum of Science + Industry

On-Demand Transport

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Space Realm (Phoenix Approach)

Focus of this Presentation

"Satlets"

Create new satellite morphology of "cells" to allow on orbit assembly at 10x reduction in $/mass

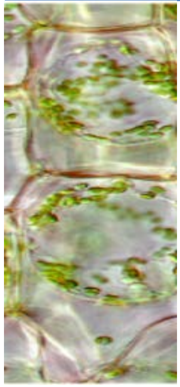
"PODs"

Create a "FedEx™ to Space" market, take advantage of every kg available, worldwide

"Robotic Servicer-Tender"

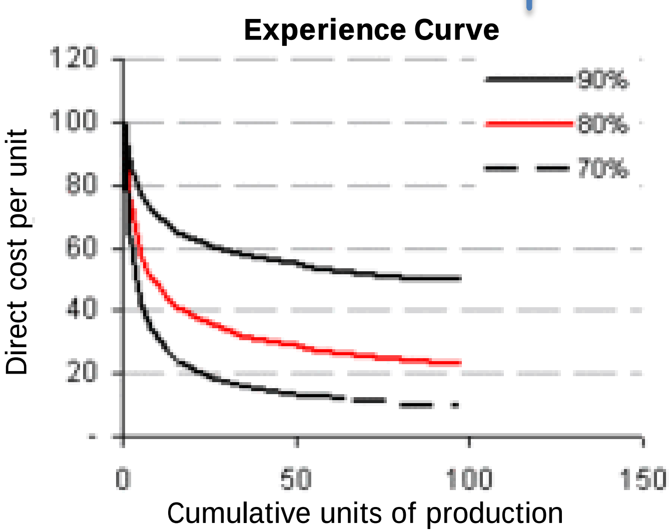
Create robotic capability to allow for on-orbit assembly, repair, integration

Assemble-able elements for space? Biology shows us a way...

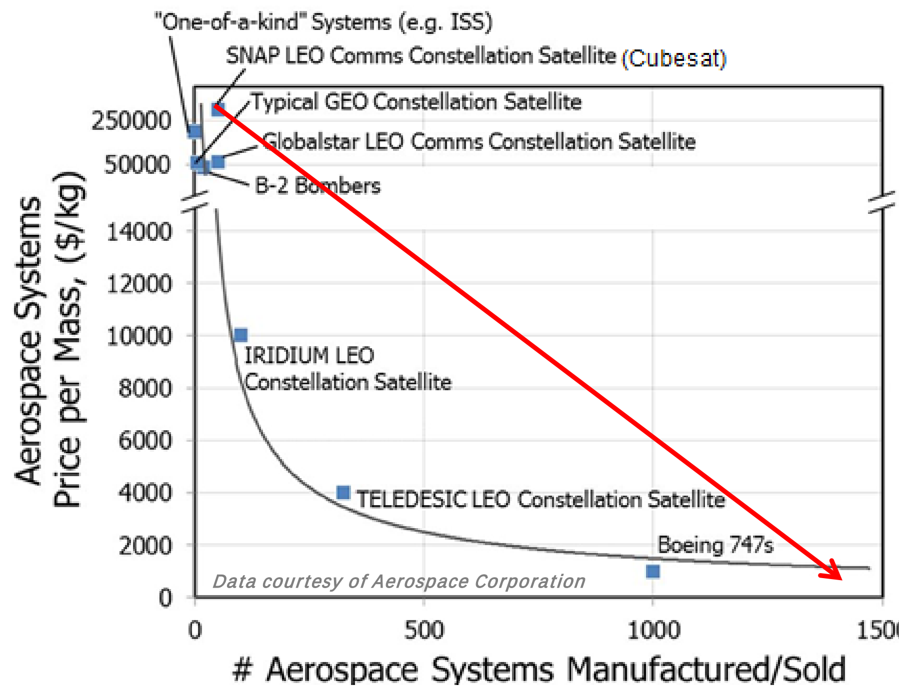


Biology aggregates specialty cells for performance at various scales.	# of Specialty Cell Types	Typical Cell Total
Placozoa	4	Few thousand
Hydra	15	50-70,000
Jellyfish	22	Several Million
Satellite	~8*	~8-25

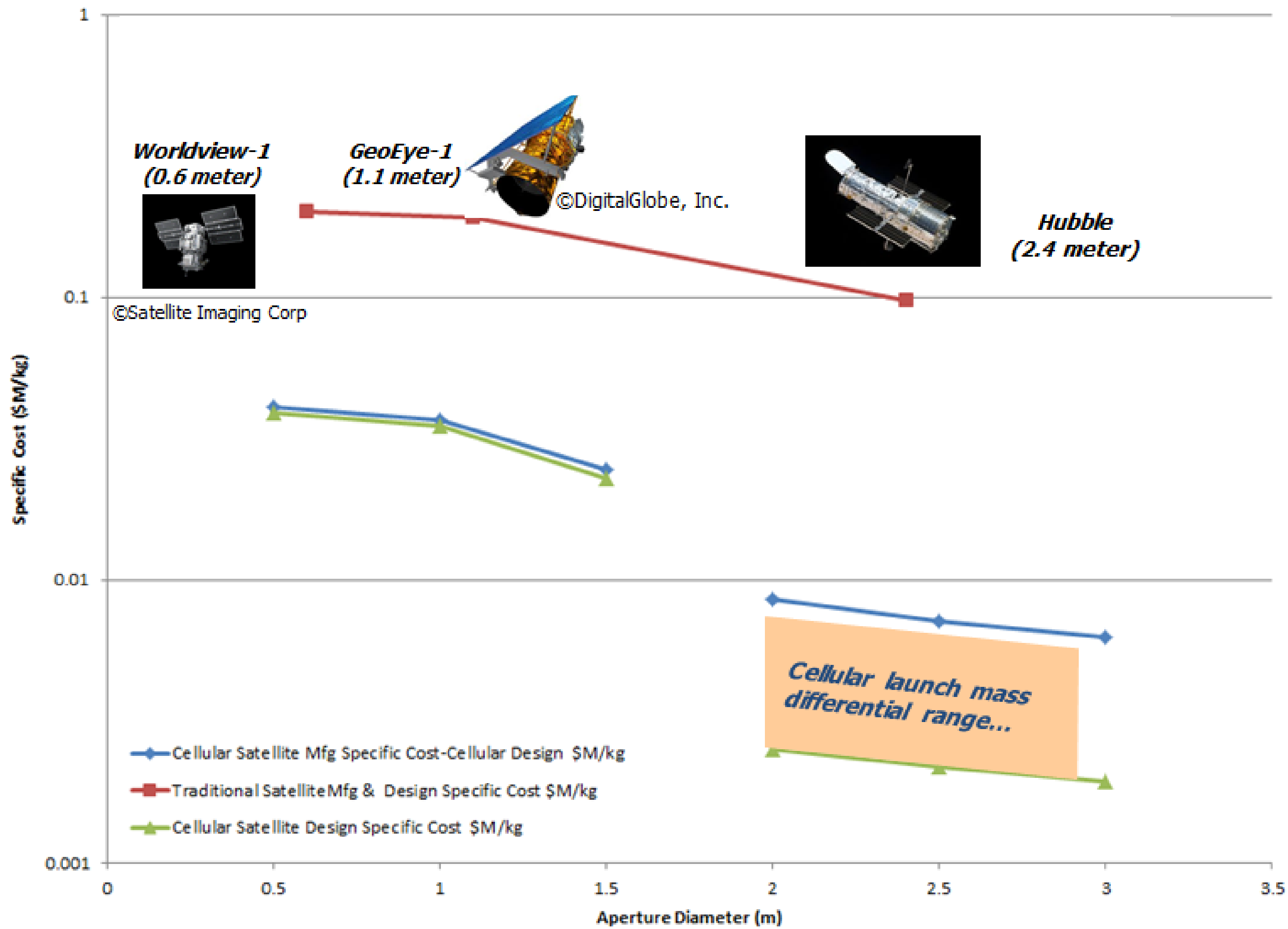
Satellite subsystems that could be "cellularized", e.g.	Mapping a Biological analogy (e.g. Hydra)
Power subsystem	Hydrostatic skeleton
Attitude control, secondary structure	Muscles
Attitude determination	Sensory
Telemetry, tracking and control	Nettles
Command and data handling	Nerves
Thermal subsystem	Interstitial
Primary structure	Glands
Propulsion	Cilia



By disaggregating each subsystem and component to its lowest "specialization" cell, **high volume manufacturing learning curves from non-traditional aerospace industries** can be applied to satellites.



First estimate of how production could change cost for a Cellular vs. Traditional architecture: Optical Systems



Mass producible sub-satellite units (satlets) could enable the first real application of industrial mass production benefits to space systems.

DARPA investing in both creation of the “satlet”, and its low-cost, high-quality production

Current Development

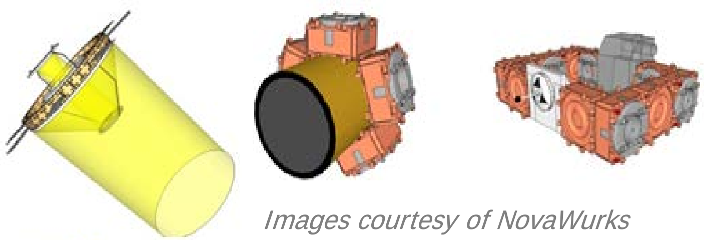
NovaWurks

Examples of two-HISat configuration options

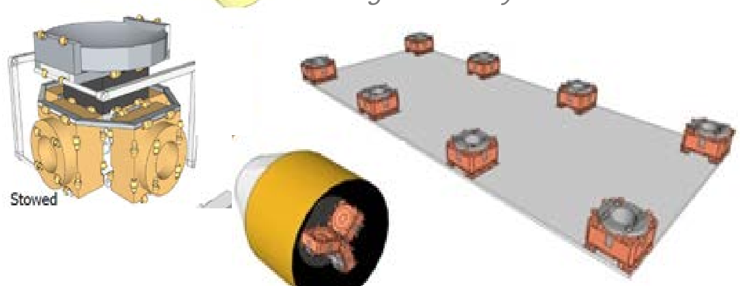
HISat pre-production hardware (Courtesy of NovaWurks)

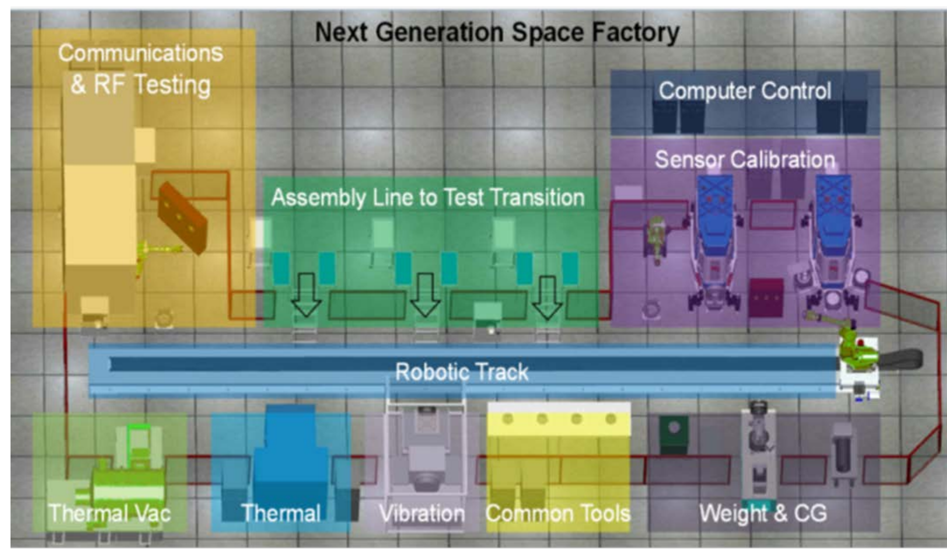
Images courtesy of Raytheon

Planned Capability

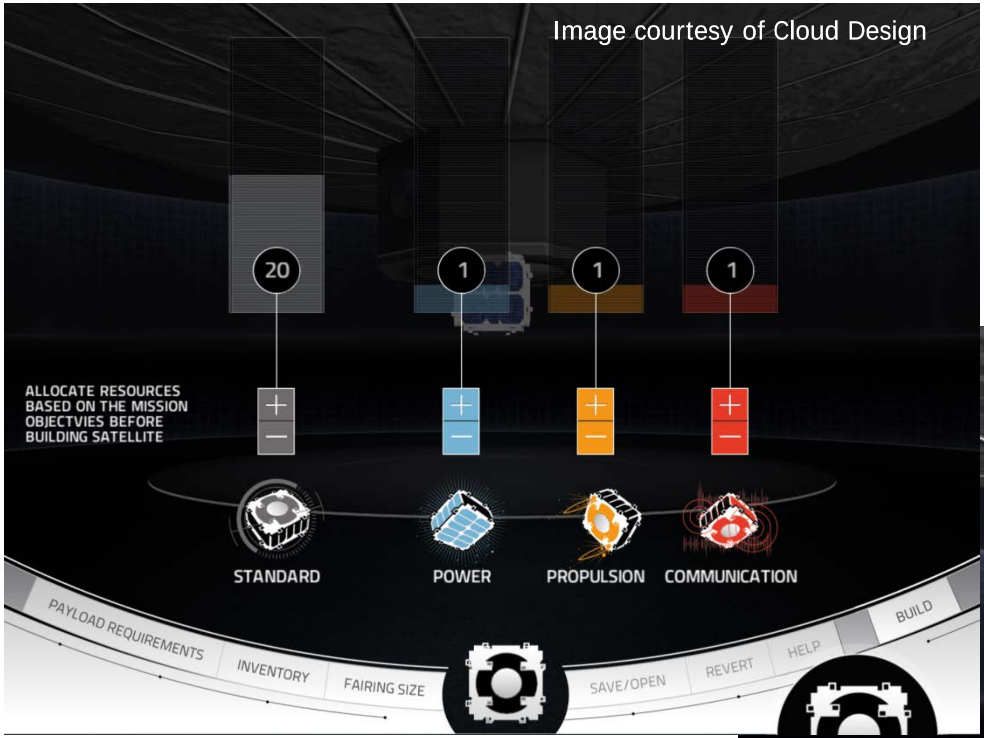


Images courtesy of NovaWurks





DARPA is developing a novel iPad "app" to democratize and explore satlet-based spacecraft design



Flight eXperiment for Cellular Integration Technology (eXCITe), planned for late 2015

- Hardware and software satlet development moving forward toward on-orbit experiment
- An example configuration of satlet LEO experiment (eXCITe) is pictured
  - Satlets shown as tan boxes
  - Radios and other external devices shown in other colors (multi-core processor, telescope, software defined radios, solar panels)
- Experiment would allow for testing of aggregation behaviors in relevant environment

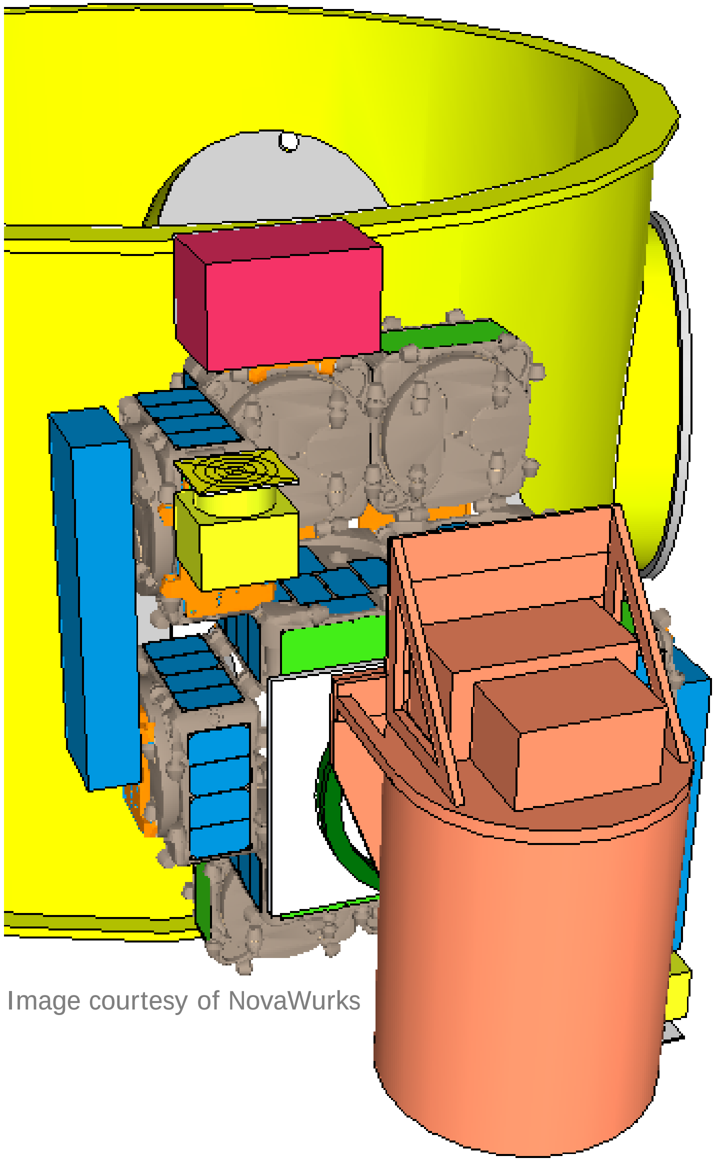
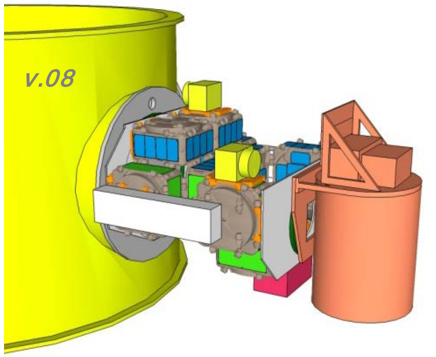
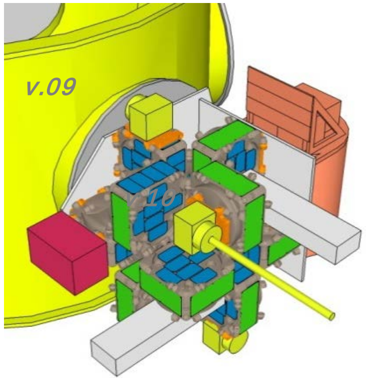


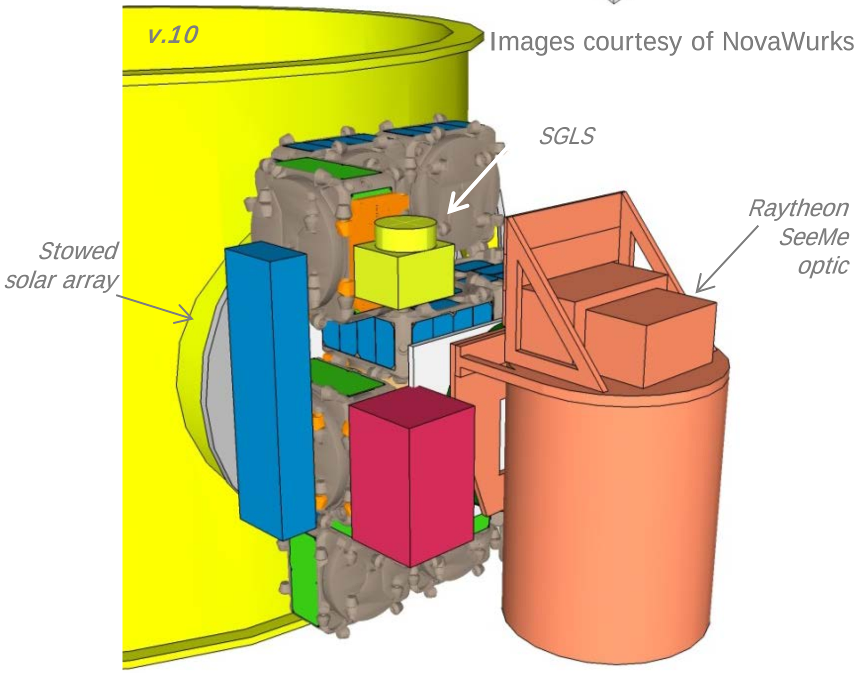
Image courtesy of NovaWurks

System design process for Satlet experiment has proven flexibility and fast payload accommodation compared to legacy design paradigm

- A few LEO experiment (eXCITe) configurations are shown
- Over two dozen configurations were evaluated in less than two weeks
- New configurations can be evaluated at any time with tools being developed.
- “Aggregation” architecture automatically adjudicates thermal and FEM analysis, *in the design*







Images courtesy of NovaWurks

Satlets enable rapid systems engineering configurations and analyses to adapt to changes in payloads and launch envelope changes and enable flexibility in designing payloads.

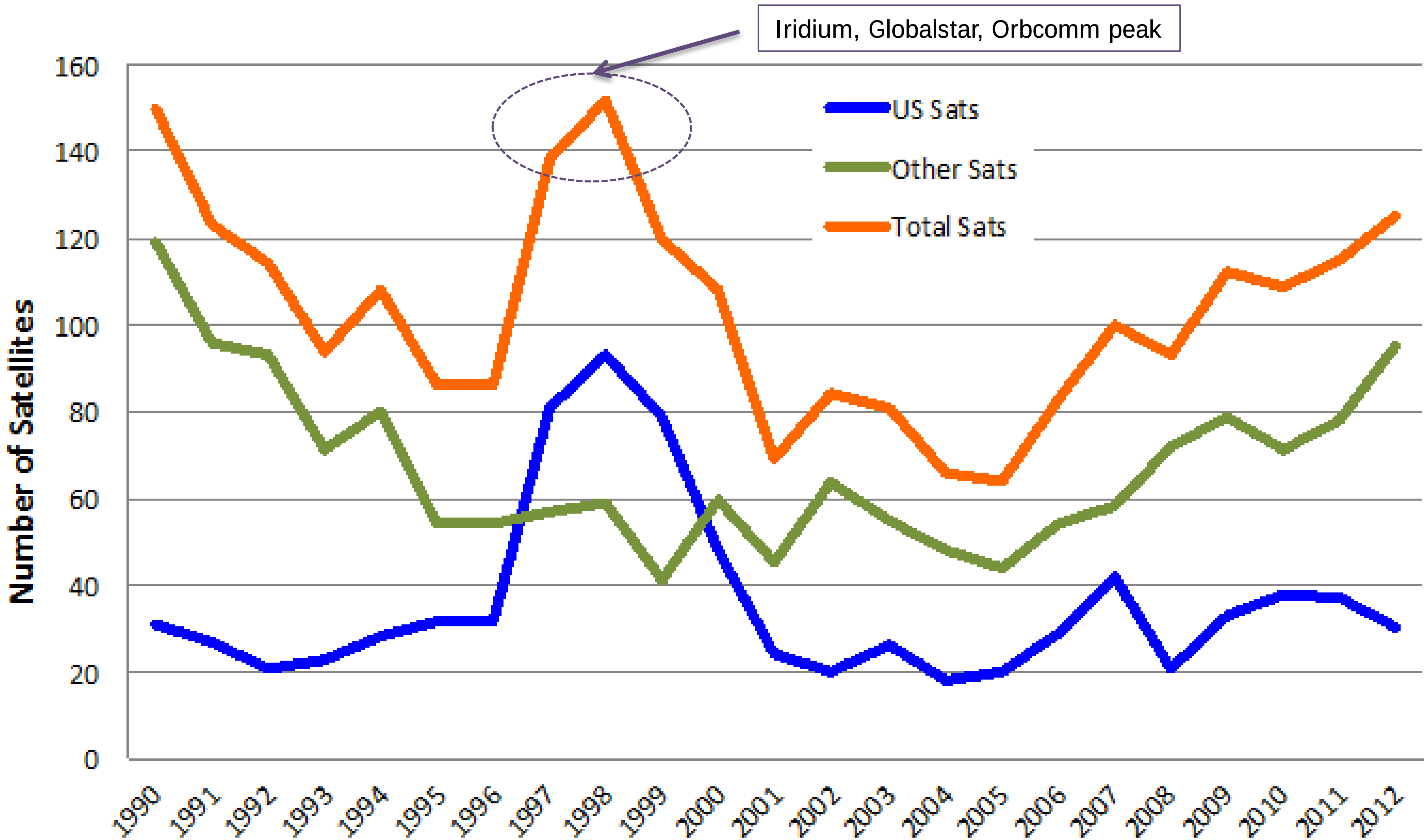
Analysis Used World Data 1990 -present

SSR COSPAR	SSR NORAD	SSR Name	SSR Launch Date	Joint Launch Mass (kg)	Mission1	Original Country	Joint Launch Country	JSR UN State of Registery	Launch Vehicle Type	Joint Spacecraft Bus	Manufacturer	Joint Design Life
1999-004D	25624	GLOBALSTAF	2/9/99	450	LEO Comm	United States	Kazakhstan		Soyuz U/Ikar	LS-400	Space System	7.5
1999-005A	25626	GALAXY 26 (	2/15/99	3,674	GEO Comm	United States	Kazakhstan	US	Proton K/DM	FS-1300	Space System	12
1999-006A	25630	JCSAT 6	2/16/99	2,900	GEO Comm	Japan	USA	JAPAN	Atlas 2	HS-601	Hughes	14
1999-008B	25635	ORSTED	2/23/99	61	Space Physics	Denmark	USA		Delta 2	Orsted	CRI of Kobenh	1
1999-008C	25636	SUNSAT	2/23/99	60	Amateur Radi	South Africa	USA	DEN	Delta 2	Sunsat	Stellenbosch U	1
1999-008A	25634	ARGOS	2/23/99	2,700	Ion engine	United States	USA	US	Delta 2	ARGOS	Boeing	3
1999-009A	25638	ARABSAT 3A	2/26/99	2,708	GEO Comm	Saudi Arabia	France		Ariane 4	Spacebus 300	Alcatel Space	15
1999-009B	25639	SKYNET 4E	2/26/99	1,490	GEO Comm	United Kingdom	France	UK	Ariane 4	ECS/OTS	Matra Marconi	10
1999-010A	25642	RADUGA 1-4	2/28/99	1,965	GEO Comm	Russia	Kazakhstan	RF	Proton K/DM	Raduga-1	NPO Prikladnoi	3

SSR COSPAR	SSR NORAD	Joint Status	Joint Operator/Owner	Joint Launch Country	Intended Orbit	Est Design Lifetime (yrs)	JSR UN Name	DC Power (W)	Est Total Cost ($M)	Est Sat Cost ($M)	Est Launch Cost ($M)
1999-004D	25624	Inactive	Globalstar	Kazakhstan	LEO	7.5		1,100	25	15.5	9
1999-005A	25626		Loral Skynet	Kazakhstan	GEO	12	[Telstar 6]	8,100	220	150	70
1999-006A	25630		JSAT - Japan S	USA	GEO	14	JCSAT 6	5,000	200	100	100
1999-008B	25635		Danish Meteor	USA	LEO	1		54			
1999-008C	25636	Inactive	Stellenbosch U	USA	LEO	1	Oersted		5	2.5	2.5
1999-008A	25634		USAF SMC/TE	USA	LEO	3	[ARGOS]		272	217	55
1999-009A	25638	Inactive	Arabsat	France	GEO	15		6,400	207	150	57
1999-009B	25639		UK MoD	France	GEO	10	SKYNET-4E	1,200	139	82	57
1999-010A	25642		Russian Minist	Kazakhstan	GEO	3	Raduga-1				70

- Excerpt from the data set.
- Data collected from multiple resources (see paper).
- Manned missions and launches without satellites were removed from dataset
- Only launches from January 1990 – present are used

Satellites Launched Per Year (1990-2012)



“Satletizing” a Percent of Historical Spacecraft Dry Mass

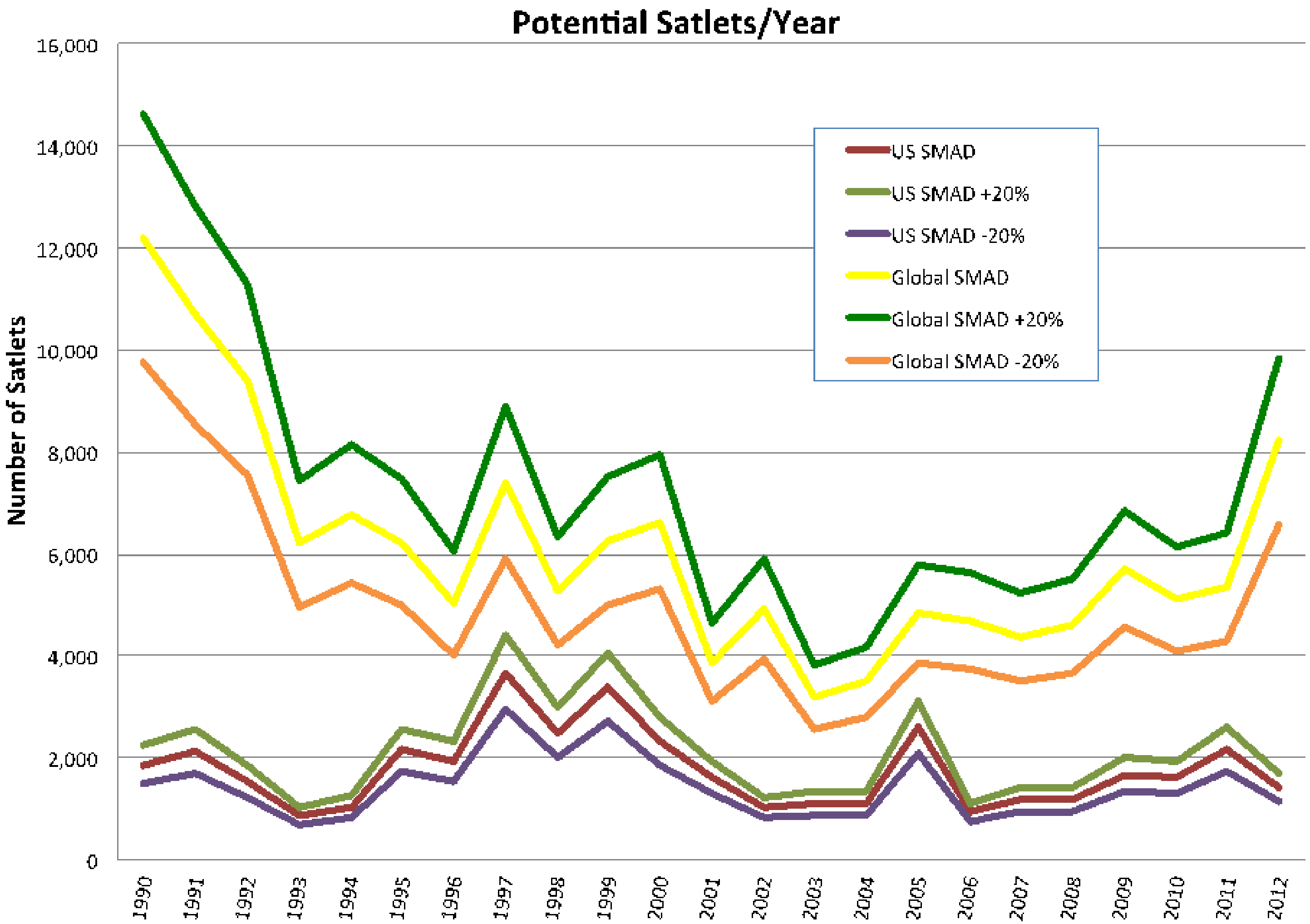
- Used approximations of subsystem mass, coupled with spacecraft mass in the database to produce “satletiz-able” mass.
- Satlets range in mass from 4kg to 10kg to date, so an average of 7.5kg is used.
- Power is supplied with small satlet-attached arrays

Average % of spacecraft dry mass	No Propulsion	LEO Propulsion	High Earth	Planetary
Payload	41	31	32	15
Structures and Mechanisms	20	27	24	25
Thermal Control	2	2	4	6
Power	19	21	17	21
TT&C	2	2	4	7
Onboard processing	5	5	3	4
Attitude Determination & Control	8	6	6	6
Propulsion	0	3	7	13
Other	3	3	3	3
Total	**100**	**100**	**100**	**100**
Propellant (% addition)	0	27	72	110

Data from *Space Mission Engineering: The New SMAD*, James Wertz

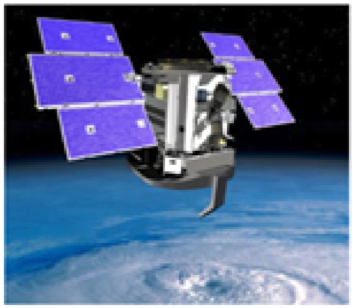
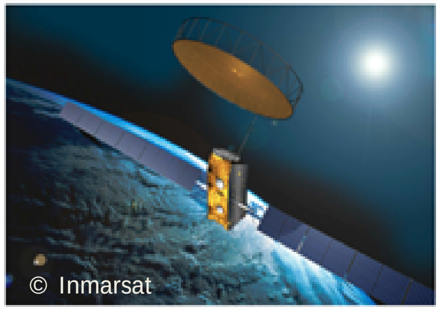
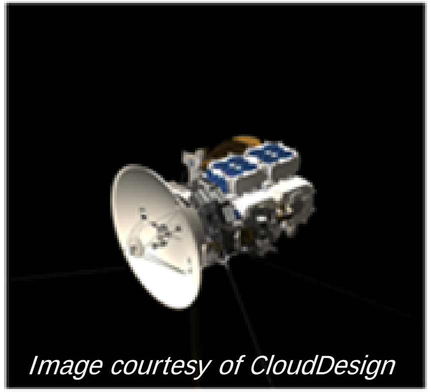
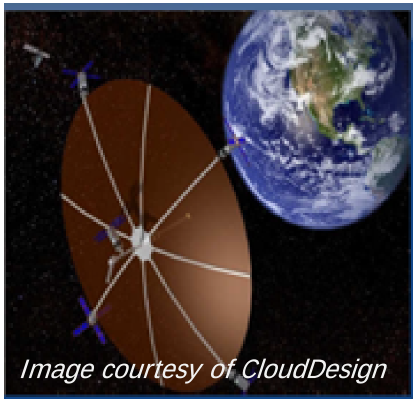
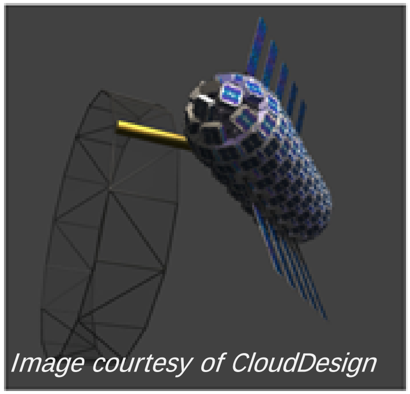
- Assumptions:
  - Launch vehicle did not change
  - Satletized system reconstitutes original system and no benefits are taken for potential improved performance/reliability
  - Propulsion capability of satlets not taken into account

Resulting No. Satlets relative to Historical Spacecraft Dry Mass



Satlets provide potential path to production quantities (>1000) year over year and could provide the means to lower cost or provide means to enable more systems to be funded in any given year.

Satlet architecture is intended to change the cost calculus of current/future space systems

Micro Satellites	Mini Satellites	Medium Satellites	Large Satellites
 © Planetary Resources	 © SSTL		 © Inmarsat
Planetary Resources (~50kg)	SSTL 300 S1 (~350kg)	NASA CloudSat (~850kg)	Inmarsat (>5000kg)
Traditional Satellite Examples (cost includes representative bus and payloads)			
10-100 kg $2-$10M*	100-500kg $10-$50M	500-1000 kg $50-$100M	>1000kg $100M-$1B+
 *Image courtesy of CloudDesign*	 *Image courtesy of CloudDesign*	 *Image courtesy of CloudDesign*	 *Image courtesy of CloudDesign*
Cellular Examples (cost and cell count payload dependent)			
3-15 cells $500K-$5M *	15-40+ cells $5-$20M	40+ $10M+	80+ $25M+

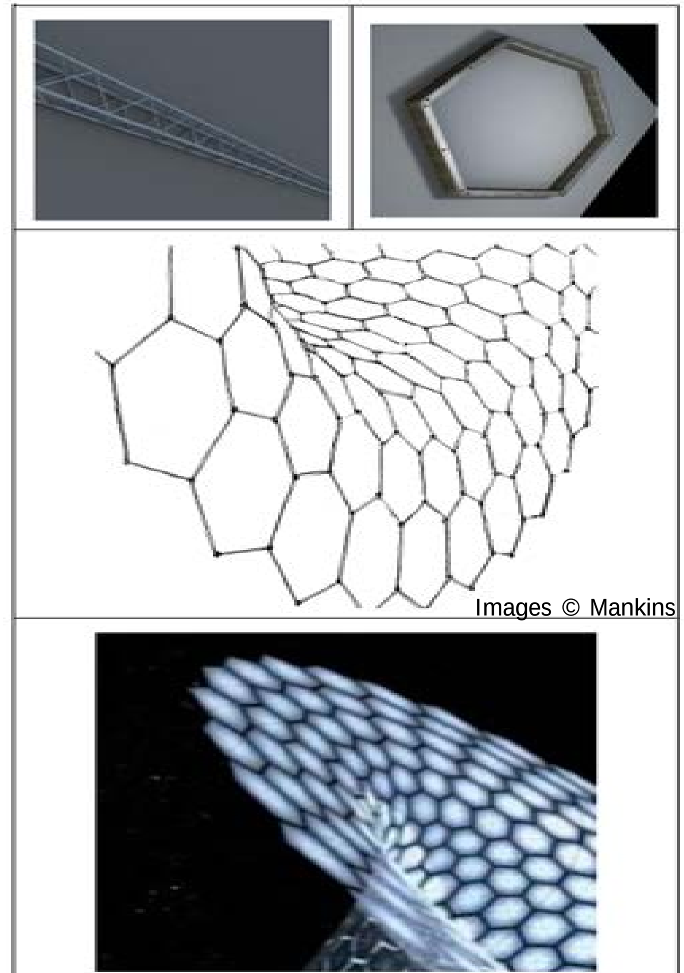
Conclusions and Future Work

- DARPA Phoenix is driving forward to verification and validation of satlet morphology in hardware, software, and interfaces.

- Satlets potential production estimated at 1,000 -16,000 per year based on historical satellite launch data.

- Cost estimates for satlets show potential for 10x or higher reduction in cost for satellites hardware only. Impact on other non-recurring tasks such as integration, mission software, etc. is expected.

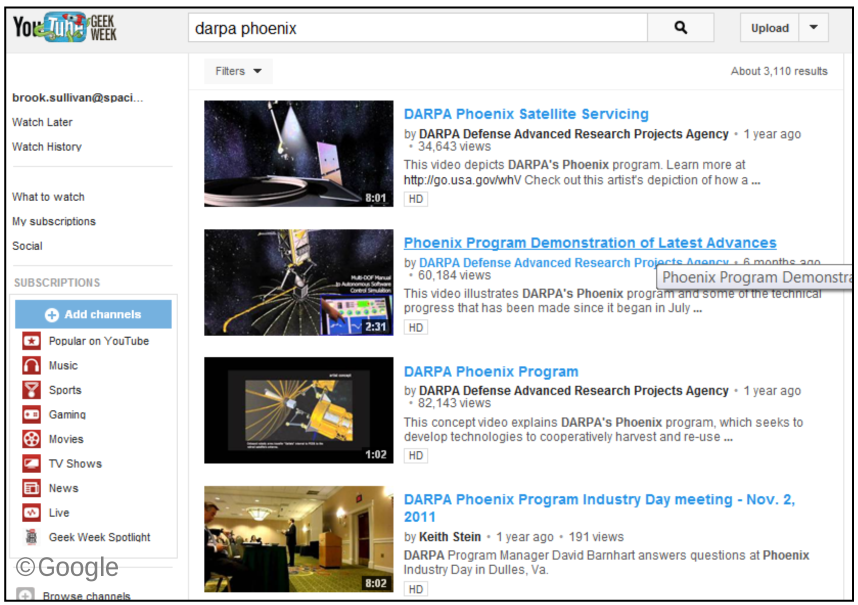
- Upcoming launch is designed to provide experience with the satlet aggregation behaviors as well the mechanism to develop and prepare for release of a standard I/F.



Satlet architecture and costs could enable new missions and new design ideas for future space systems.

More information

- Phoenix DARPA Homepage
  - http://www.darpa.mil/Our_Work/TTO/Programs/Phoenix.aspx
- Phoenix videos on YouTube,
  - search: DARPA Phoenix
- **Questions?**



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